ANALYSIS OF THE DOSE-RESPONSE RELATIONSHIP BETWEEN DURATION AND POSTURE OF SITTING ON THE INTENSITY OF LOWER BACK PAIN IN MEDICAL STUDENTS: A LONGITUDINAL STUDY WITH A REPEATED MEASURES APPROACH

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Abstrak

Nyeri punggung bawah (*low back pain*/LBP) sering dialami mahasiswa kedokteran akibat durasi duduk yang lama dan postur duduk yang tidak ergonomis, yang meningkatkan tekanan intradiskal serta ketegangan otot paraspinal. Penelitian ini bertujuan menganalisis hubungan *dose response* antara durasi duduk, postur duduk, dan intensitas LBP pada mahasiswa preklinik secara longitudinal. Studi dilakukan selama 14 hari terhadap 201 mahasiswa dengan tiga kali pengukuran (*Pre, Mid, Post*). Durasi duduk diukur menggunakan DDA, postur duduk menggunakan ASPQ, dan intensitas LBP menggunakan BPBM–VAS. Analisis data menggunakan metode GEE AR(1). Hasil menunjukkan durasi duduk (p = 0,018), postur duduk (p < 0,001), serta interaksi durasi duduk dan postur (p = 0,048) berpengaruh signifikan terhadap LBP. Postur yang baik menurunkan nyeri, sedangkan durasi duduk tinggi dengan postur buruk meningkatkan nyeri. Temuan ini menegaskan pentingnya penerapan ergonomi, jeda aktivitas, dan fasilitas belajar yang mendukung pencegahan LBP.

Kata Kunci: *Nyeri Punggung Bawah, Durasi Duduk, Postur Duduk, Mahasiswa Kedokteran, Dose–Response, Ergonomi, Studi Longitudinal, Pengukuran Berulang*.

Abstract

Low back pain (LBP) is common among medical students due to prolonged sitting and non-ergonomic posture, which increase intradiscal pressure and paraspinal muscle tension. To assess the dose–response relationship between sitting duration, sitting posture, and LBP intensity in preclinical students longitudinally. A 14-day study involving 201 students with three measurements (Pre, Mid, Post). Sitting duration was assessed using DDA, posture using ASPQ, and LBP using BPBM–VAS. Analysis used GEE AR(1) to assess main effects and interactions. Sitting duration (p = 0.018), posture (p < 0.001), DDA-ASPQ interaction (p = 0.048), and TIMEDDA, ASPQ interaction (p = 0.023) significantly affected LBP. Good posture reduced pain, while high sitting duration with poor posture increased progressive pain. Results were consistent in the Gamma–Log and Tweedie–Log models. This study shows that lower back pain is influenced by the interaction between sitting duration and posture. Prolonged sitting with poor posture increases pain, while ergonomic posture reduces its impact. These findings emphasise the importance of ergonomic education, movement breaks, and learning facilities that support pain prevention.

Keywords: *Low Back Pain, Sitting Duration, Sitting Posture, Medical Students, Dose–Response, Ergonomics, Longitudinal Study, Repeated Measures*

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INTRODUCTION

Low back pain (LBP) remains one of the most prevalent musculoskeletal disorders and a leading cause of disability worldwide. According to the Global Burden of Disease report, more than 600 million individuals are affected by LBP globally, with a continued increase observed particularly among young and working-age populations (Yang et al., 2025). LBP consistently ranks among the top contributors to years lived with disability (YLDs) across various regions, including among university students and young professionals (The Lancet Rheumatology, 2023). Such trends highlight LBP as a growing public health concern, especially within populations exposed to prolonged sitting and sedentary academic or occupational environments.

Medical students represent a particularly vulnerable group due to demanding academic workloads, extended periods of sitting during lectures, self-study, and computer-based tasks, as well as habitual non-ergonomic sitting postures. Evidence from systematic reviews indicates that sedentary behavior and prolonged unsupported sitting are significantly associated with increased biomechanical stress on the lumbar spine, contributing to the development and progression of LBP (Shrestha et al., 2021). In addition, postural factors such as slumped sitting, increased lumbar flexion, and inadequate back support have been shown to elevate spinal loading and muscular tension, further heightening the risk of musculoskeletal discomfort

Biomechanical studies have demonstrated that variations in pelvic tilt, lumbar support, trunk inclination, and hip alignment influence the compressive forces exerted on spinal structures. Sitting in a flexed posture or without appropriate lumbar support increases intradiscal pressure and paraspinal muscle activation, thereby exacerbating lumbar strain (Huang et al., 2022). Recent research among university students similarly indicates that extended sitting durations combined with poor sitting posture are strongly correlated with increased reports of LBP (Rahman et al., 2025). Sensor-based studies further suggest that individuals experiencing LBP tend to maintain static positions for longer periods, leading to greater cumulative spinal loading over time (Martinez-Valdes et al., 2024).

However, despite extensive evidence, the majority of previous studies have employed cross-sectional designs, limiting the ability to capture temporal patterns of pain progression or establish dose–response relationships between sitting duration, posture, and LBP intensity. Given that musculoskeletal symptoms often fluctuate over time and may worsen cumulatively with repeated exposure, a longitudinal approach is required to more accurately examine how daily sitting habits contribute to changes in LBP among medical students.

Therefore, this study aims to investigate the dose–response relationship between sitting duration, sitting posture, and the intensity of lower back pain among preclinical medical students using a longitudinal repeated-measures design (Pre, Mid, Post). By incorporating validated measurement tools and observing changes across multiple time points, this research provides a more comprehensive understanding of how temporal variations in sitting behavior influence LBP intensity. The findings are expected to inform preventive ergonomic strategies within medical education settings and contribute to early musculoskeletal health promotion among students

METHOD

This study is a longitudinal study conducted to evaluate the relationship between sitting duration, sitting posture, and lower back pain intensity in preclinical medical students at the Faculty of Medicine, Gorontalo State University. The research process was carried out over 14 days with three measurements, namely on the first day (baseline), the 7th day, and the 14th day

The research respondents consisted of medical students in the medical education study program who met the inclusion criteria: active status, in the preclinical stage, and provided written consent after receiving an explanation of the research objectives and procedures. Exclusion criteria included a history of spinal injury, chronic musculoskeletal disorders, or medical conditions that affect functional activities. Total sampling was used to ensure representation of the entire target population, and demographic data such as age, gender, and body mass index were recorded for further analysis

The study used a repeated measures design, allowing each participant to be measured at three time points. The three main variables assessed included:

1. Sitting duration, measured using the Daily Duration of Activity (DDA), a documented instrument that has been proven valid in assessing daily activity patterns.

2. Sitting posture, assessed using the Academic Sitting Posture Questionnaire (ASPQ), which has been widely used to assess ergonomic posture in academic activities.

3. Lower back pain intensity, measured using the Back Pain Baseline Measure–Visual Analogue Scale (BPBM-VAS), based on previously published pain assessment methods.

These instruments are only summarized in this study, while their validity and reliability refer to the original publications of each measurement tool.

All participants followed the same research procedures. At baseline, respondents received the DDA, ASPQ, and BPBM-VAS questionnaires and

instructions on how to fill them out correctly. Re-measurements were conducted on day 7 and day 14 at the same time to minimize temporal bias. During the study period, respondents were asked to maintain their academic activities and daily habits as usual, without additional intervention, to ensure that the results reflected natural conditions.

These research procedures were approved by the Ethics Committee of the Faculty of Medicine, Gorontalo State University, and participants signed informed consent forms before data collection was conducted

Data were analyzed using repeated measures tests to evaluate changes in sitting duration, sitting posture, and lower back pain intensity over three time periods. The significance level was set at $p \leq 0.05$. Additional analysis was performed using the Generalized Estimating Equations (GEE) approach when the data pattern showed peculiarities that required a generalized linear mode

RESULT AND DISCUSSION

This study involved 201 preclinical medical students from the Faculty of Medicine, State University of Gorontalo, who participated in three sessions (Pre, Mid, and Post) evaluated at 7-day intervals The majority of respondents were female (67.7%), with a mean age of 18.86 ± 1.12 years, and most had a body mass index (BMI) within the normal category (57.7%). These characteristics were relatively homogeneous and align with the general demographic profile of preclinical medical students in Indonesia. The demographic distribution of the study sample is presented in Table 1.

Table 1. Demographic Profile of the Sample

	Category	Frequency (n)	Presentase (%)
Age	17	22	10.9%
	18	60	29.9%
	19	56	27.9%
	20	52	25.9%
	21	9	4.5%
	22	2	1.0%
Total		**201**	**100%**
Gender			
Male		65	32.3%
Female		136	67.7%
Total		**201**	**100%**
IMT			
Normal		116	57.7%
Obesitas		25	12.4%
Overweight		28	13.9%
Underweight **Total**		32	15.9%
		201	**100%**

Descriptive analysis showed that the Daily Duration of Activity (DDA) among students was 15.57 ± 4.99 hours per day, indicating that preclinical medical students spend a substantially long time in a seated position, primarily due to high academic demands. This value markedly exceeds the sitting exposure threshold recommended by the World Health Organization (<8 hours per day) to

prevent long-term musculoskeletal consequences. The average Academic Sitting Posture Questionnaire (ASPQ) score was 32.86 ± 4.02, suggesting that most students demonstrated moderate to good postural awareness. The intensity of low back pain, measured using the Visual Analog Scale (VAS), had a mean of 2.05 ± 2.17 with a right-skewed distribution (positive skewness = 1.045), indicating that the majority of respondents experienced mild or no pain, although a small proportion reported moderate to severe pain.

Table 2. Frequency Distribution of Each Variable

Parameter	Mean	SD	Skewness
DDA	15,57	4,99	0,789
ASPQ	32,86	4,02	0,156
VAS	2,05	2,17	1,05

Data on n=603 (observation data from 3 measurements). The Kolmogorov–Smirnov and Shapiro–Wilk normality tests indicated that all three variables were not normally distributed ($p < 0.05$). Therefore, a Generalized Estimating Equations (GEE) model with a Normal–Identity family–link and an AR(1) correlation structure was employed to capture the longitudinal dynamics across repeated measurement time points within the same individuals. The final model included the time variable (TIME), sitting duration (DAILY DURATION OF ACTIVITY), sitting posture (ASPQ), and all two-way and three-way interaction terms.

The initial GEE model using non-centered DDA and ASPQ variables exhibited extreme multicollinearity ($r \approx \pm 0.999$), which resulted in distorted standard errors and invalid interaction p-values. As a methodological remedy, the continuous variables DDA and ASPQ were mean-centered (DDA_C and ASPQ_C) before being entered into the model. After centering, the correlations among interaction parameters and main effects decreased substantially (approaching zero), thereby validating the final GEE model.

Table 3. Tests of Model Effects from the GEE Analysis

Efek	Wald χ²	df	p	Significance
Time				
DDA_C	1,528	2	0,466 0,018 0,01	Insignificance
ASPQ_C	5,568	1	0,327 0,104 0,048 0,023	Significance
TIME	*11,560	1		Significance
DDA_C	2,238	2		Insignificance
TIME	*4,518	2		Insignificance
ASPQ_C	3,925	1		Significance
DDA_C	*7,551	2		Significance
ASPQ_C				
TIME *				
DDA_C *				
ASPQ_C				

The results of the model effects test (Type III Wald Chi-Square) indicated that sitting duration (DDA_C; p = 0.018), sitting posture (ASPQ_C; p < 0.001), the two-way interaction DDA_C*ASPQ_C *(p = 0.048), and the three-way interaction*

TIMEDDA_CASPQ_C (p = 0.023) had significant effects on low back pain intensity. In contrast, the main effect of time (p = 0.466) and its two-way interactions with the primary variables (TIMEDDA_C; p = 0.327 and TIME*ASPQ_C; p = 0.104) were not significant, indicating that temporal changes in pain were more strongly influenced by the combined effects of sitting duration and posture rather than by time itself

Table 4. Parameter Estimates

Effect	B	SE	p
(*Intercept*)	1,976	1,654	0,000
DDA_C	0,015	0,31	0,018
ASPQ_C	-0,58	0,294	0,05
DDA_C * ASPQ_C	-0,22	0,007	0,002
TIME=2 * DDA_C * ASPQ_C	0,022	0,009	0,008
TIME=3 * DDA_C * ASPQ_C	0,02	0,007	0,011

The estimated parameter values showed that the model constant was 1.976 (p < 0.001), representing the baseline mean intensity of low back pain at the initial time point. The variable DDA_C had a coefficient of 0.015 (p = 0.638), indicating that sitting duration alone was not significantly associated with pain after adjusting for other variables. In contrast, ASPQ_C had a coefficient of –0.058 (p = 0.050), suggesting that a one-unit increase in sitting posture score was associated with a 0.058-point reduction in low back pain on the VAS scale.

The twoway interaction DDA_C*ASPQ_C yielded a significant negative coefficient of –0.022 (p = 0.002), meaning that the effect of increased sitting duration on pain was attenuated when students maintained better sitting posture. In other words, ergonomic posture serves as a protective factor against the negative impact of prolonged sitting. Furthermore, the three-way interaction TIME*DDA_C*ASPQ_C showed significant coefficients at two measurement points, namely 0.020 (p = 0.008) for Mid and 0.022 (p = 0.011) for Post. These findings indicate that the relationship between sitting duration, sitting posture, and pain intensity is not constant but changes dynamically over time.

Sensitivity analyses using Gamma–Log and Tweedie–Log models demonstrated consistent directions of association and levels of significance with the primary model. This consistency strengthens the conclusion that the study findings are robust despite violations of normality assumptions and the positive skewness characteristic of VAS data.

Table 5. Tests of Model Effects from the GEE Gamma–Log and Tweedie–Log Analyses

Effect	GEE Gamma-Log			GEE Tweedie-Log		
	Wald χ^2	df	p	Wald χ^2	df	p
Time						
DDA_C	0,777	2	0,650,02	1,059	2	0,590,02
ASPQ_C	5,111	1	0,00	5,255	1	0,00

TIME *		0,290,080,0			0,050,080,0	
DDA_C	12,471	1	5	14,17	1	0
TIME *			0,00			0,00
ASPQ_C	2,447	2		4	2	
DDA_C*	4,999	2		5,924	2	
ASPQ_C	3,774	1		4,948	1	
TIME *						
DDA_C*	10,807	2		6,854	2	
ASPQ_C					17,05 4	

The dynamic pattern of changes in pain intensity over time, influenced by Sitting Duration and Sitting Posture, can be more clearly interpreted through the estimated marginal means (EMMeans) presented in the three-way interaction plot.

The EMMeans graph shows that at the initial measurement (Pre), differences in pain scores across combinations of sitting duration and posture were relatively small. Students with long sitting duration and poor posture exhibited slightly higher VAS scores compared to other groups, although the difference was not clinically significant. However, by the first week of measurement (Mid), divergence between the curves began to appear: the group with prolonged sitting duration and poor posture demonstrated a more rapid increase in pain scores compared to other groups, whereas students with better posture tended to maintain stable pain levels.

This increase continued into the second week (Post), during which the gap between the interaction lines widened further. Students with high sitting duration (>15 hours/day) and poor posture showed a sharp rise in VAS scores nearly double that of students with moderate sitting duration and good posture. In contrast, students with ergonomic posture maintained low VAS scores despite increased sitting duration, indicating a strong moderating effect of posture on the musculoskeletal burden of prolonged sitting.
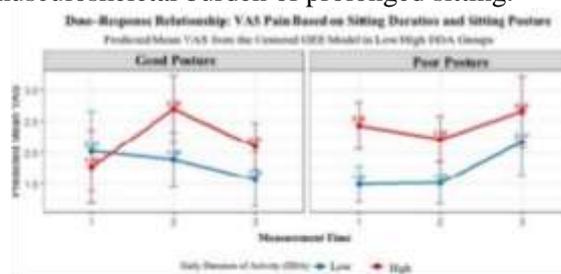

Figure 1. rPlot of Estimated Marginal Means (EMMeans)

Visually, the EMMeans plot demonstrates a cross-over interaction pattern between posture quality and time. Differences in pain intensity at the initial measurement were relatively small, but increased sharply in the poor-posture group during the Post phase. These findings indicate a temporal dose–response effect, in which prolonged sitting in poor posture contributes to a cumulative rise in pain intensity. Conversely, maintaining good sitting posture tends to stabilize or reduce pain intensity over time.

This phenomenon aligns with the theory of cumulative load and the muscle-fatigue hypothesis, which state that repeated static mechanical pressure from prolonged sitting increases tissue tension, reduces blood supply to the paraspinal muscles, and heightens pain sensitivity. Longitudinally, the accumulation of mechanical stress results in discomfort that may progress into musculoskeletal pain if not offset by muscle relaxation or postural adjustments. In the context of medical students, intensive academic activities such as reading, typing assignments, and attending online lectures exacerbate these conditions by increasing exposure to long periods of static posture (Claus et al., 2018).

The findings of this study also reinforce empirical evidence that postural interventions have a protective effect against musculoskeletal symptoms. Lis et al. (2019) reported that sitting with >30° lumbar flexion significantly increases the risk of low back pain among students and office workers, whereas upright sitting with symmetrical weight distribution can reduce intradiscal pressure by up to 25%. An intervention study by Szeto et al. (2021) similarly found that two weeks of ergonomic posture training reduced low back pain intensity by 35% without significant changes in sitting duration. These findings are consistent with the EMMeans patterns observed in the present study, where the good-posture group maintained stable pain levels even after two weeks of prolonged sitting exposure.

From a medical education perspective, these findings have direct implications for health-promotion strategies within academic environments. Preclinical medical students face long and repetitive academic sitting demands, particularly under online learning formats and problem-based learning (PBL). The combination of high cognitive load, prolonged sitting, and limited ergonomic awareness creates significant musculoskeletal risks. Therefore, integrated efforts are required, including postural ergonomics training, provision of learning facilities that match anthropometric needs, and institutional policies that encourage active breaks (microbreaks) every 45–60 minutes to prevent mechanical load accumulation.

Overall, the longitudinal analysis using the GEE model and the interpretation of EMMeans indicate that sitting duration does not directly increase low back pain; rather, its effect is moderated by sitting posture and interacts dynamically with exposure time. Good sitting posture functions as a protective factor that slows the progression of pain even during prolonged sitting periods. Thus, ergonomic posture serves not only as a lifestyle factor but also as a biological mechanism that prevents the buildup of mechanical stress on the musculoskeletal system. These findings highlight the importance of incorporating preventive ergonomic approaches into medical education curricula to preserve spinal health early

in training and reduce the risk of future chronic musculoskeletal pain.

Discussion

The findings of this study demonstrate a clear dose–response relationship between sitting duration, sitting posture, and the intensity of low back pain (LBP), in which the interaction between these factors becomes progressively stronger across the measurement period. These results support the initial hypothesis and reinforce fundamental biomechanical theories stating that prolonged static sitting increases cumulative stress on lumbar structures, reduces paraspinal muscle blood flow, and heightens pain sensitivity. The significant three-way interaction (TIME × DDA × ASPQ) indicates that pain development is not driven solely by the duration of sitting, but is strongly influenced by the quality of posture adopted during exposure, with ergonomic posture functioning as a protective factor.

When compared with previous studies, these results are consistent with existing evidence from biomechanical and observational research. Gao et al. (2023) found that lumbar load and muscle forces vary with backrest inclination and lumbar support, while sensor-based studies by McClintock et al. (2024) showed that individuals with LBP tend to adopt more static and flexed sitting postures. Additionally, systematic reviews such as Mahdavi et al. (2021) confirm that prolonged sedentary behavior increases the risk of LBP. Therefore, this study strengthens prior findings and contributes novel insights through its longitudinal design, which more accurately captures temporal changes in pain compared to cross-sectional approaches.

These findings carry important theoretical and practical implications. Theoretically, the results confirm the moderating role of posture in the relationship between sitting duration and pain, supporting cumulative load and muscle fatigue theories in musculoskeletal research. Practically, the study is highly relevant for medical education settings where students are exposed to extended periods of academic sitting. Preventive strategies including ergonomic training, scheduled active breaks every 45–60 minutes, and the provision of study facilities that meet ergonomic standards are strongly recommended to reduce the risk of LBP in students. Implementing such interventions may help minimize long-term musculoskeletal strain while improving comfort and academic productivity. Therefore, it is important for medical education institutions to organize study time so that students are not required to sit for long periods without breaks, accompanied by education on ergonomic sitting principles, the importance of physical fitness, and recommendations for stretching or changing positions periodically

CONCLUSIONS

Based on measurements and analysis of lower back pain intensity across various sitting

durations and postures, this study demonstrates a consistent dose–response relationship between sitting duration, postural quality, and increased musculoskeletal pain.

Longer sitting duration, especially when accompanied by non-ergonomic sitting posture, is associated with a progressive increase in lower back pain that occurs cumulatively over the exposure period. Longitudinal analysis also shows that the development of pain is not only influenced by sitting duration, but also by the interaction between duration and posture, which together increase paraspinal muscle tension and mechanical load on the lumbar structures. This condition indicates that academic workload and learning activities dominated by prolonged sitting among medical students at Gorontalo State University can be a significant risk factor for lower back pain. The provision of ergonomic learning facilities such as anthropometrically appropriate chairs and desks is also necessary to reduce the risk of pain. Further research should be conducted over a longer period of time, taking into account other variables such as physical activity, academic stress, and sleep quality to gain a more comprehensive understanding of the causes of lower back pain in students.

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